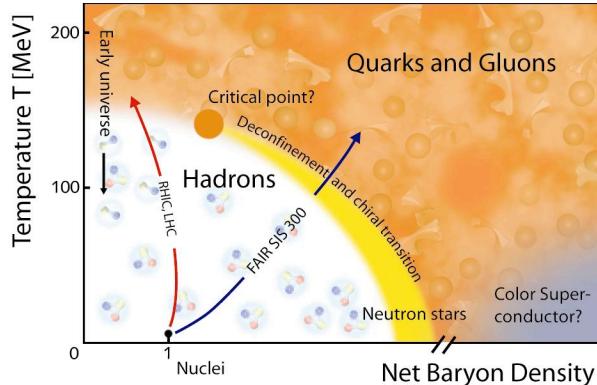


# **Physics of the Heavy Flavor Tracker at STAR**

**Nu Xu**

Nuclear Science Division  
Lawrence Berkeley National Laboratory

# STAR Physics Focus

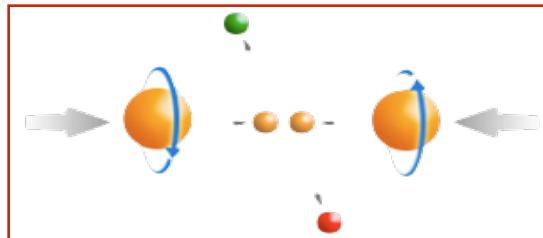


## 1) At 200 GeV top energy

- Study **medium properties, EoS**
- pQCD in hot and dense medium

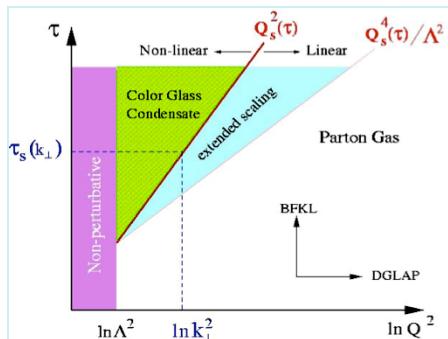
## 2) RHIC beam energy scan

- Search for the ***QCD critical point***
- Chiral symmetry restoration



## Spin program

- Study **proton intrinsic properties**

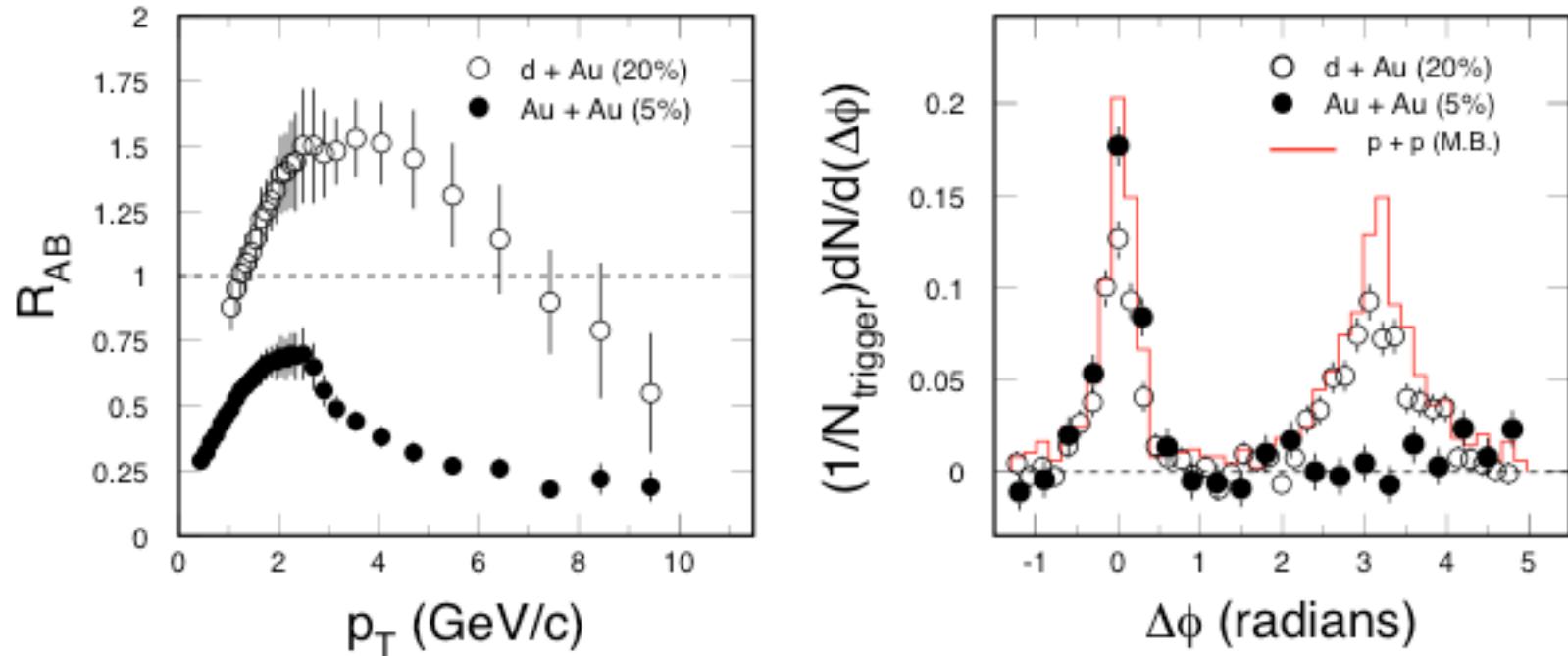


## Forward program

- Study low-x properties, search for **CGC**
- Study elastic (inelastic) processes (pp2pp)
- Investigate **gluonic exchanges**

# Partonic Energy Loss at RHIC

STAR: Nucl. Phys. **A757**, 102(2005).



Central Au+Au collisions: light quark hadrons and the away-side jet in back-to-back ‘jets’ are suppressed. Different for p+p and d+Au collisions.

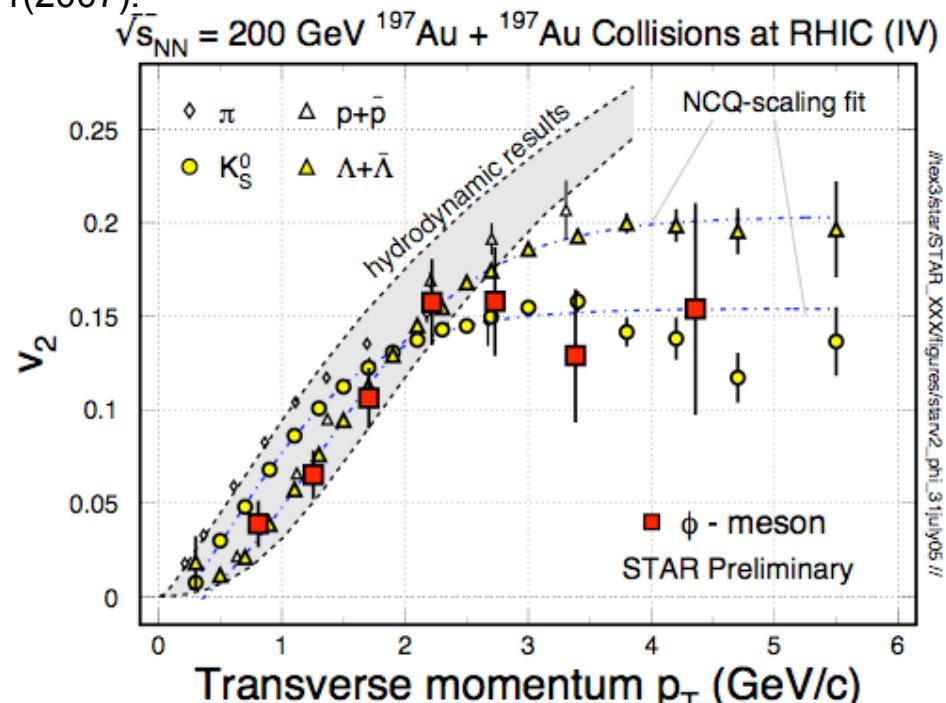
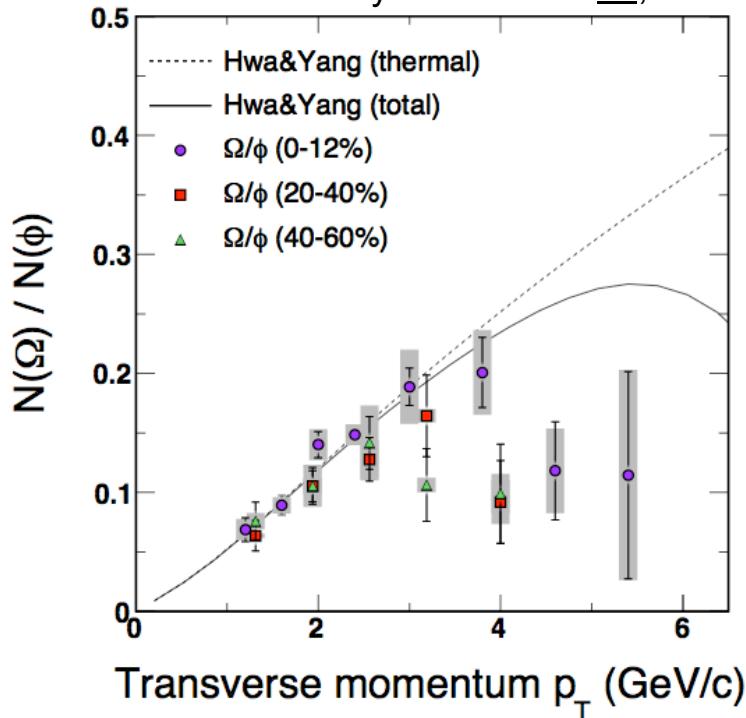
Energy density at RHIC:  $\epsilon > 5 \text{ GeV/fm}^3 \sim 30\epsilon_0$

*Explore pQCD in hot/dense medium*

*$R_{AA}(c,b)$  measurements are needed!*

# $\phi$ -meson Flow: Partonic Flow

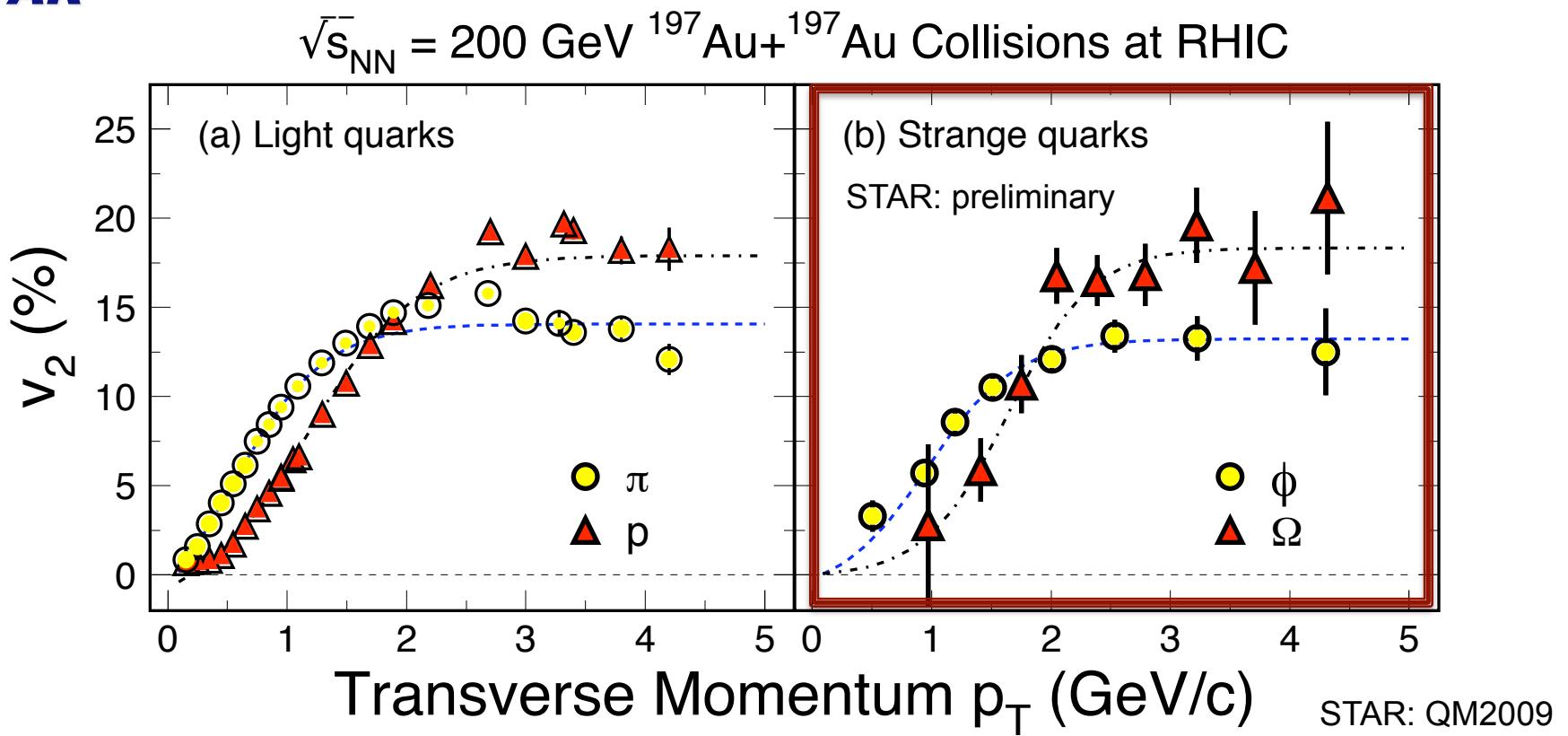
STAR: Phys. Rev. Lett. **99**, 112301(2007).



“ $\phi$ -mesons (and other hadrons) are produced via coalescence of seemingly thermalized quarks in central Au+Au collisions. This observation implies **hot and dense matter with partonic collectivity** has been formed at RHIC”

*In order to test early thermalization:  $v_2(p_T)$  of c- and b-hadrons versus  $p_T$  data are needed!*

# Partonic Collectivity at RHIC



Low  $p_T$  ( $\leq 2 \text{ GeV}/c$ ): hydrodynamic mass ordering

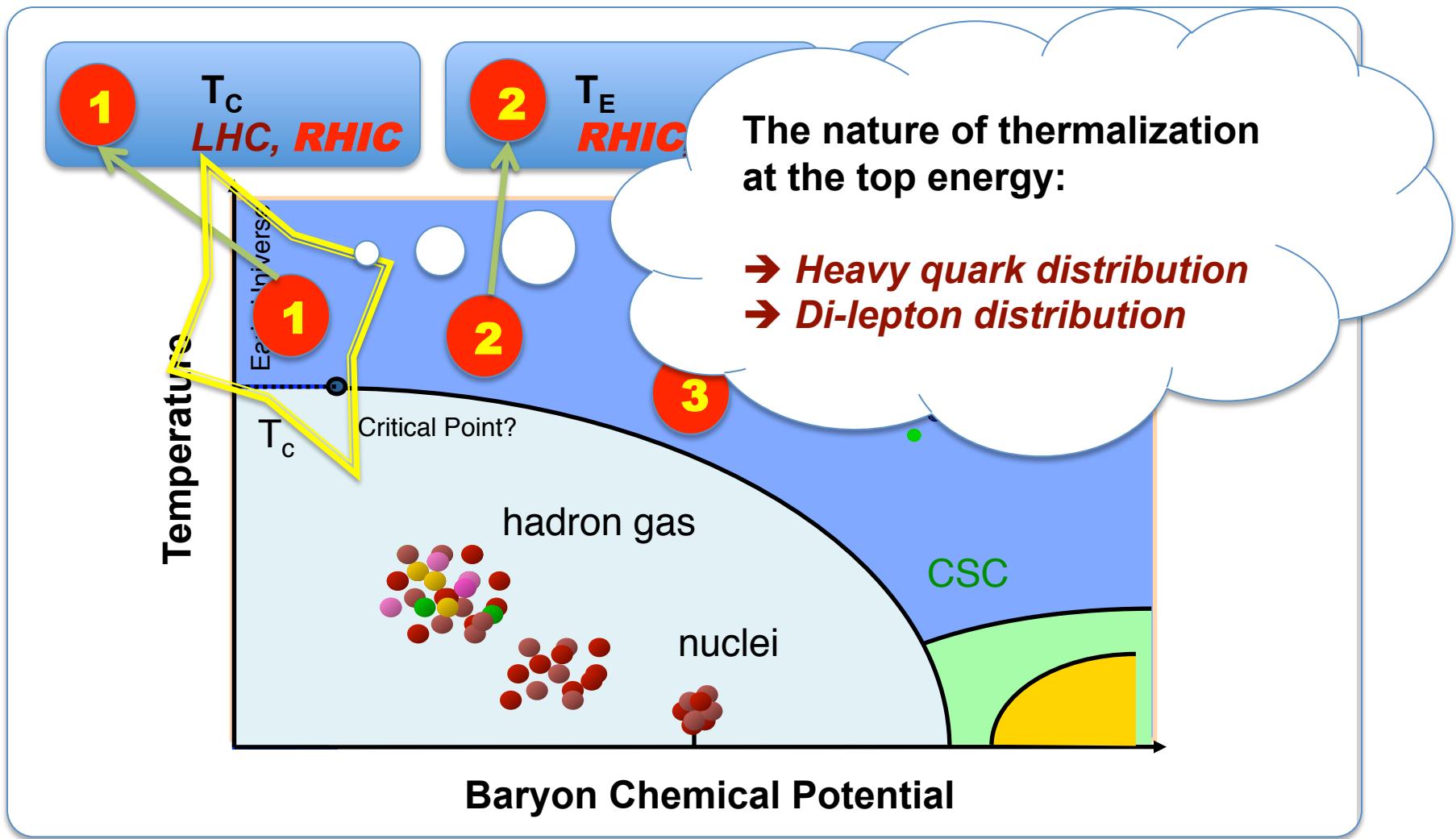
High  $p_T$  ( $> 2 \text{ GeV}/c$ ): number of quarks ordering

s-quark hadron: smaller interaction strength in hadronic medium

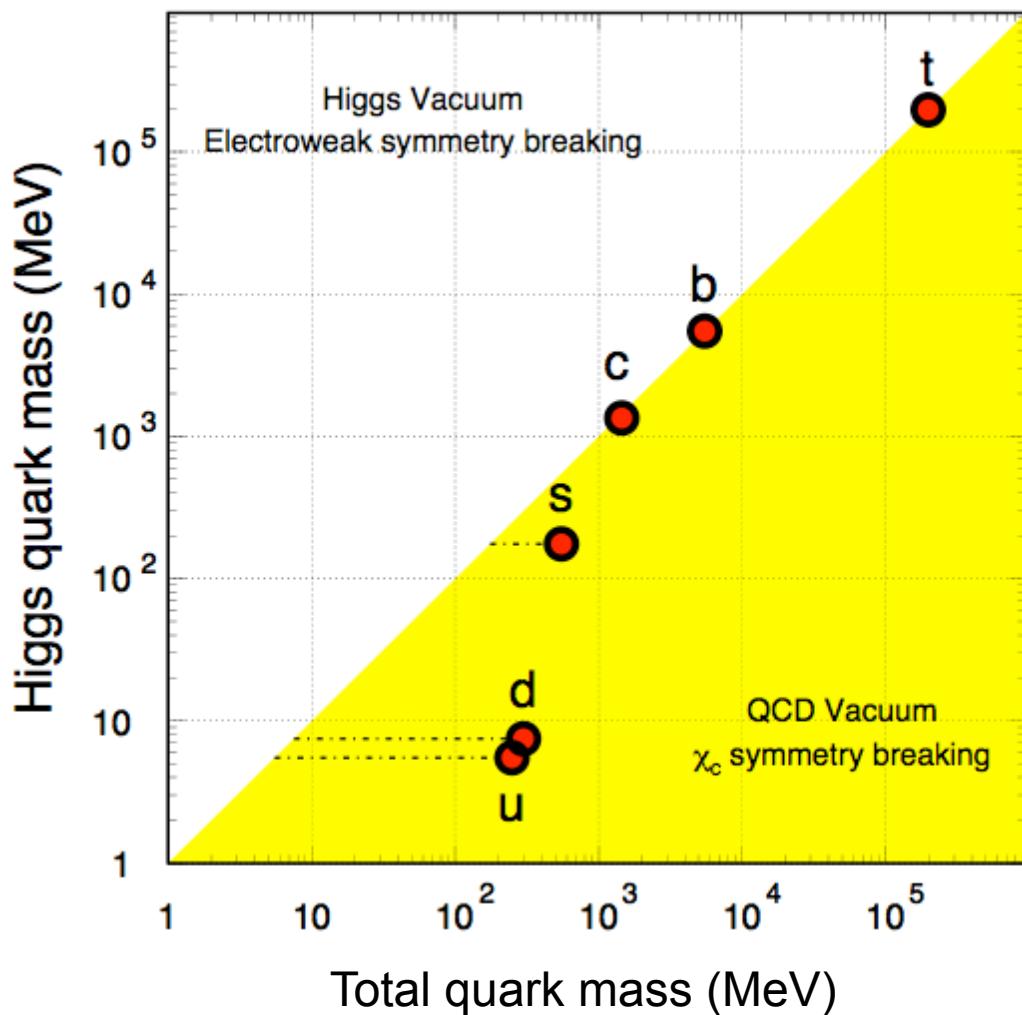
light- and s-quark hadrons: similar  $v_2$  pattern

**=> Collectivity developed at partonic stage!**

# The QCD Phase Diagram and High-Energy Nuclear Collisions



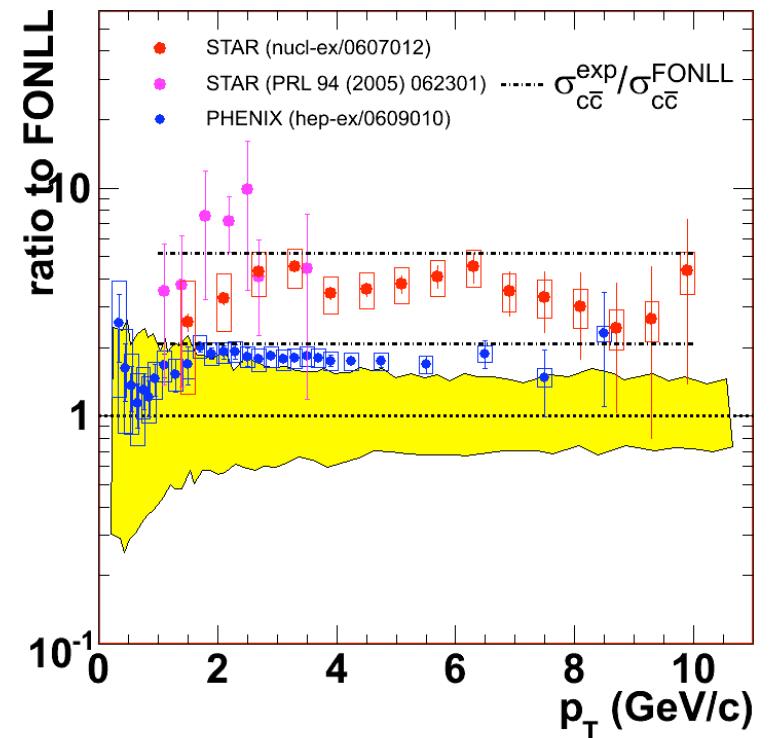
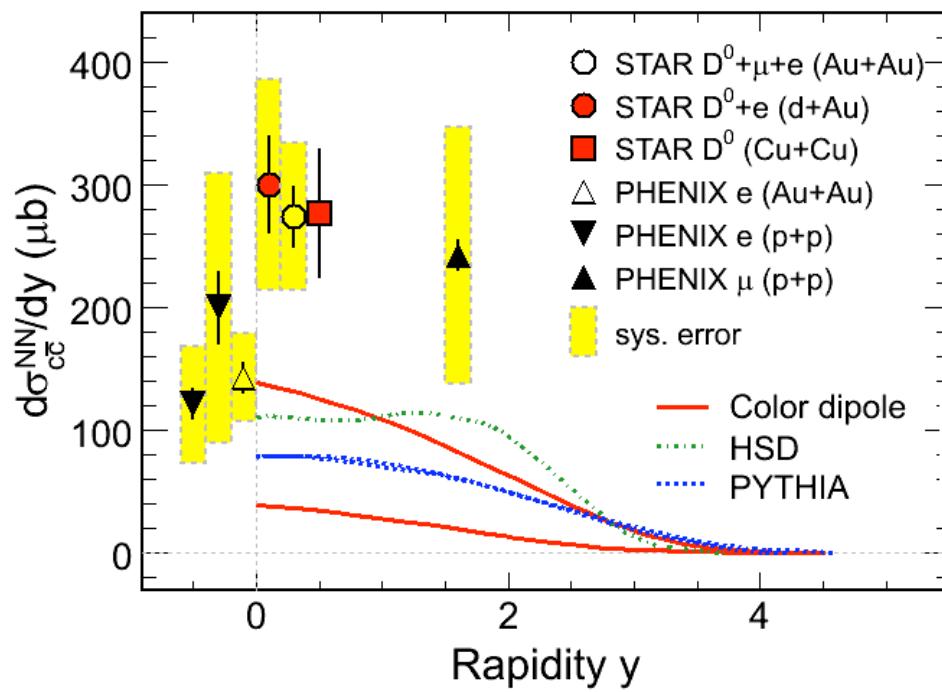
# Quark Masses



X. Zhu, et al, Phys. Lett. B647, 366(2007).

- Higgs mass: electro-weak symmetry breaking (current quark mass).
- QCD mass: Chiral symmetry breaking (constituent quark mass).
  - ⇒ Strong interactions do not affect heavy-quark mass.
  - ⇒ New scale compare to the excitation of the system.
  - ⇒ Study properties of the hot and dense medium at the ***foremost early stage*** of heavy-ion collisions.
  - ⇒ Explore pQCD at RHIC.

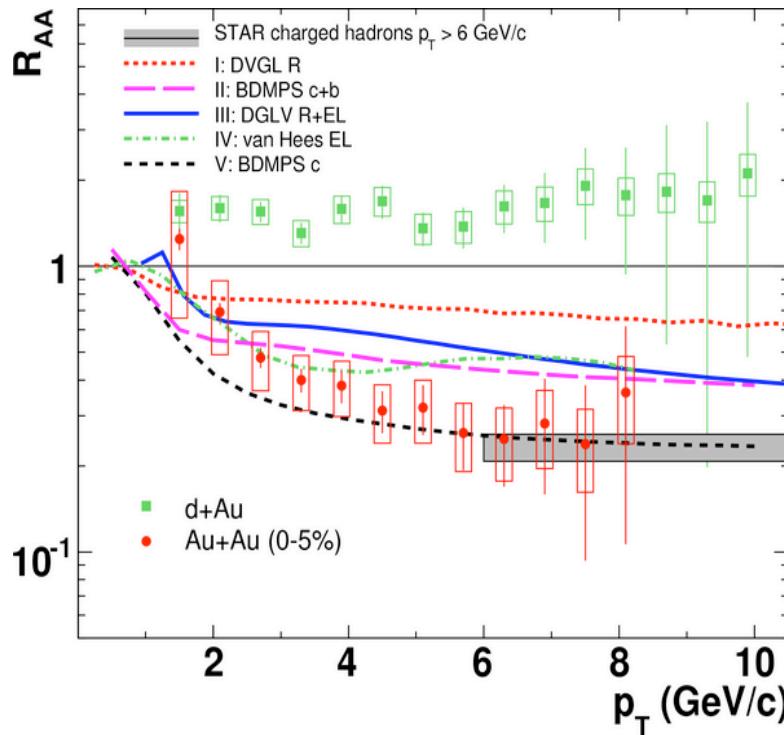
# Charm Cross Sections at RHIC



- 1) Large systematic uncertainties in the measurements
- 2) New displaced, topologically reconstructed measurements for c- and b-hadrons are needed  $\Rightarrow$  **Upgrade**

# Heavy Quark Energy Loss

STAR: Phys. Rev. Lett, **98**, 192301(2007).



1) Non-photonic electrons decayed from - charm and beauty hadrons

2) At  $p_T \geq 6 \text{ GeV}/c$ ,

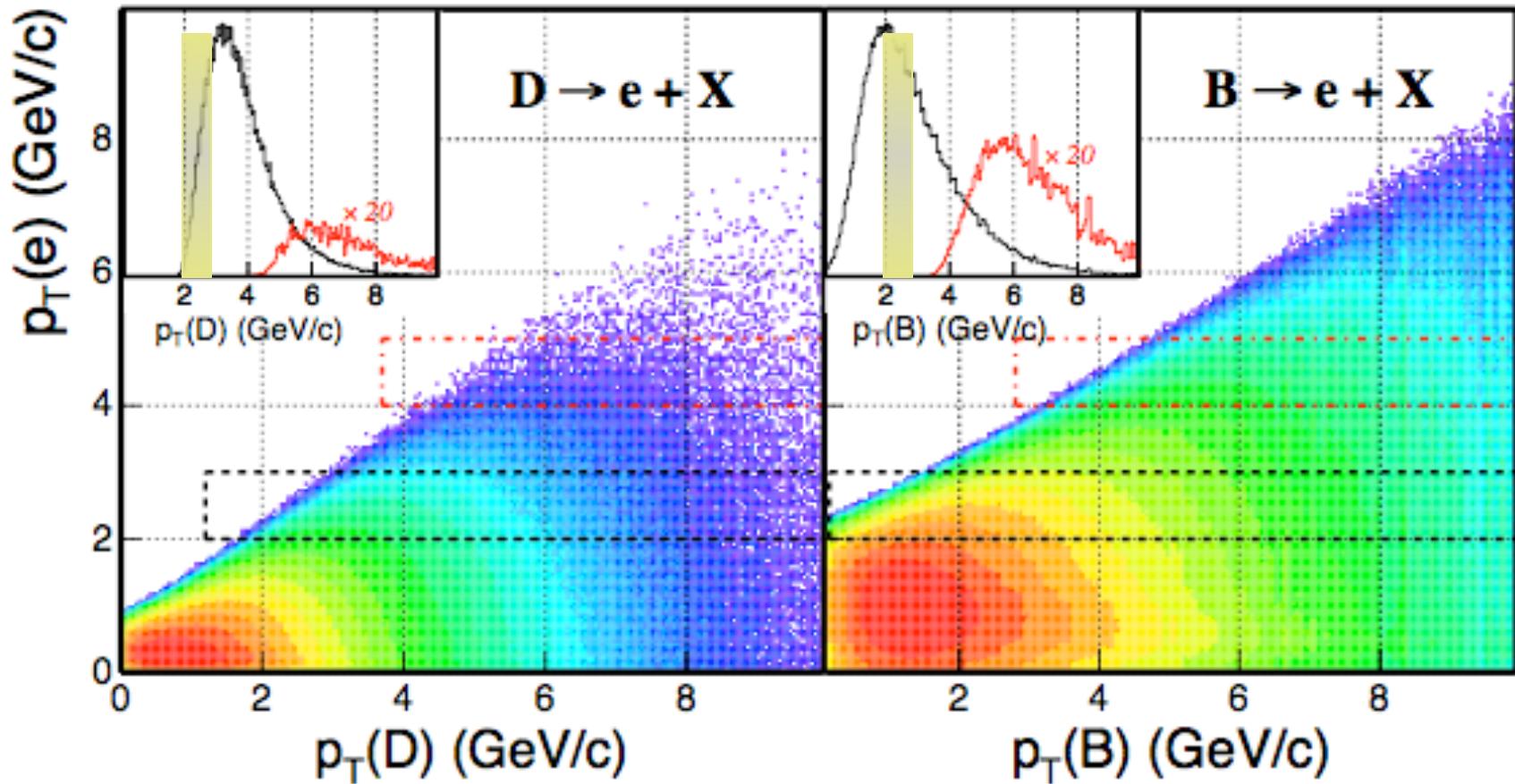
$$R_{AA}(\text{n.e.}) \sim R_{AA}(h^\pm)!$$

contradicts to naïve pQCD predictions

## Surprising results -

- challenge our understanding of the energy loss mechanism
- force us to RE-think about the collisional energy loss
- Requires direct measurements of c- and b-hadrons.**

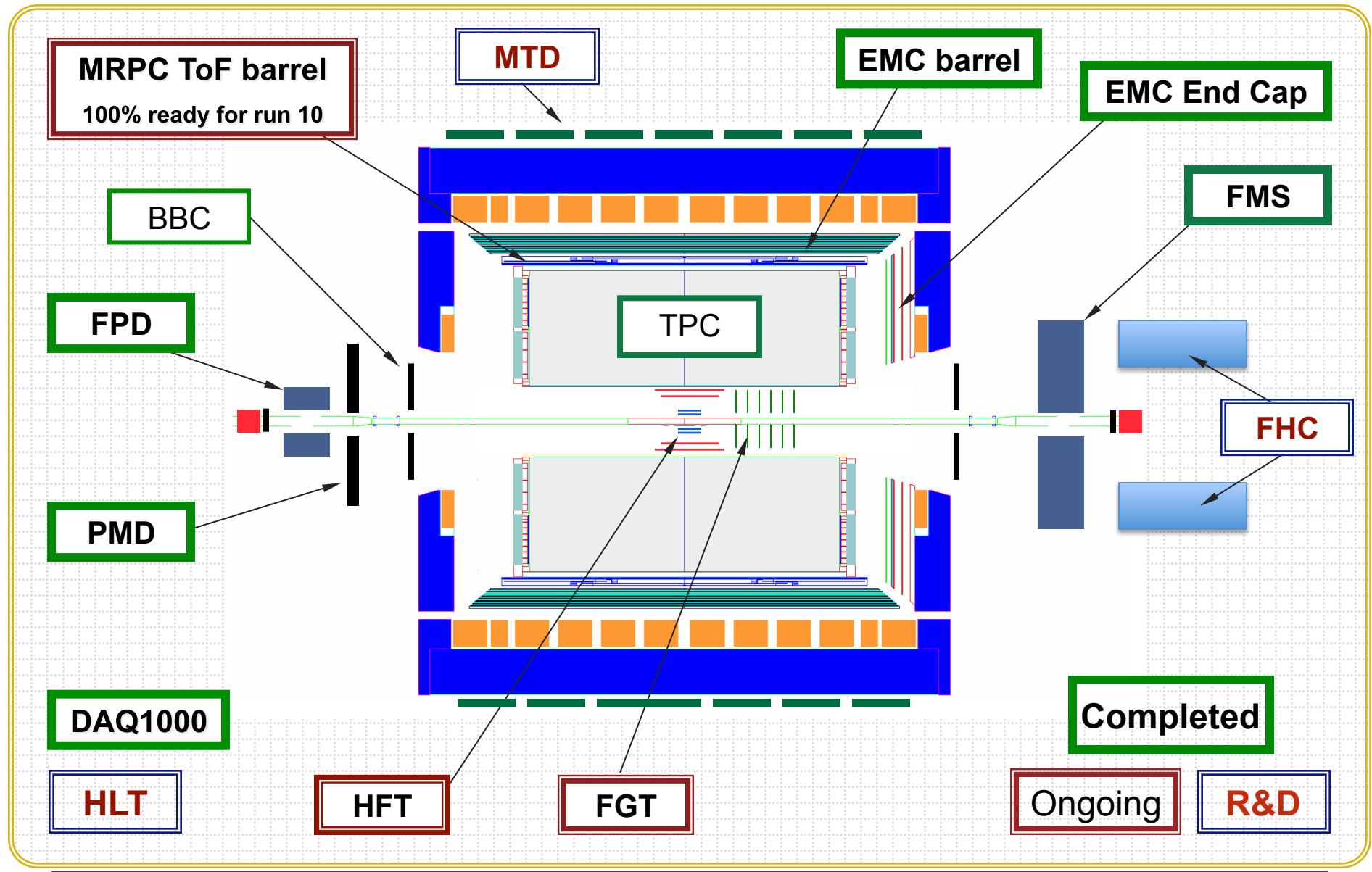
# Decay $e$ $p_T$ vs. B- and C-hadron $p_T$



Key: ***Directly reconstructed heavy quark hadrons!***

Pythia calculation Xin Dong, USTC October 2005

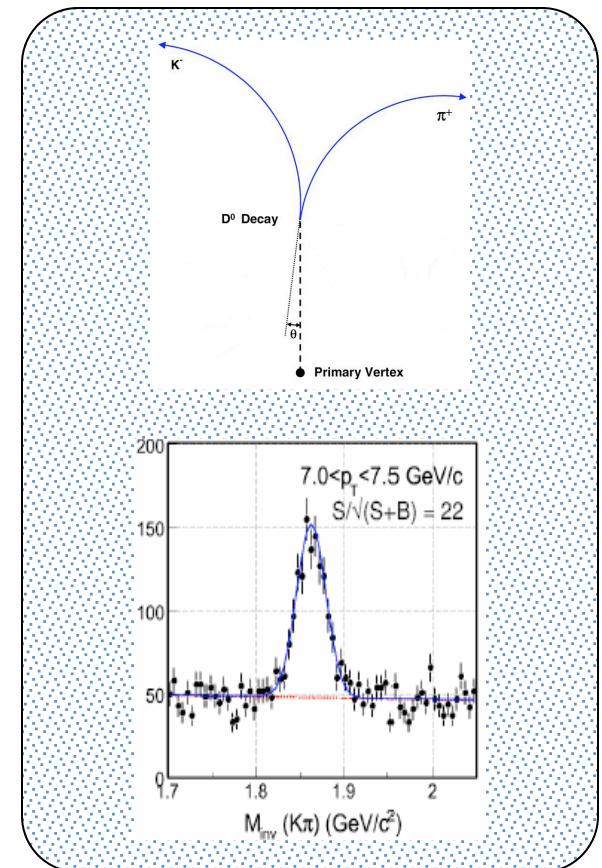
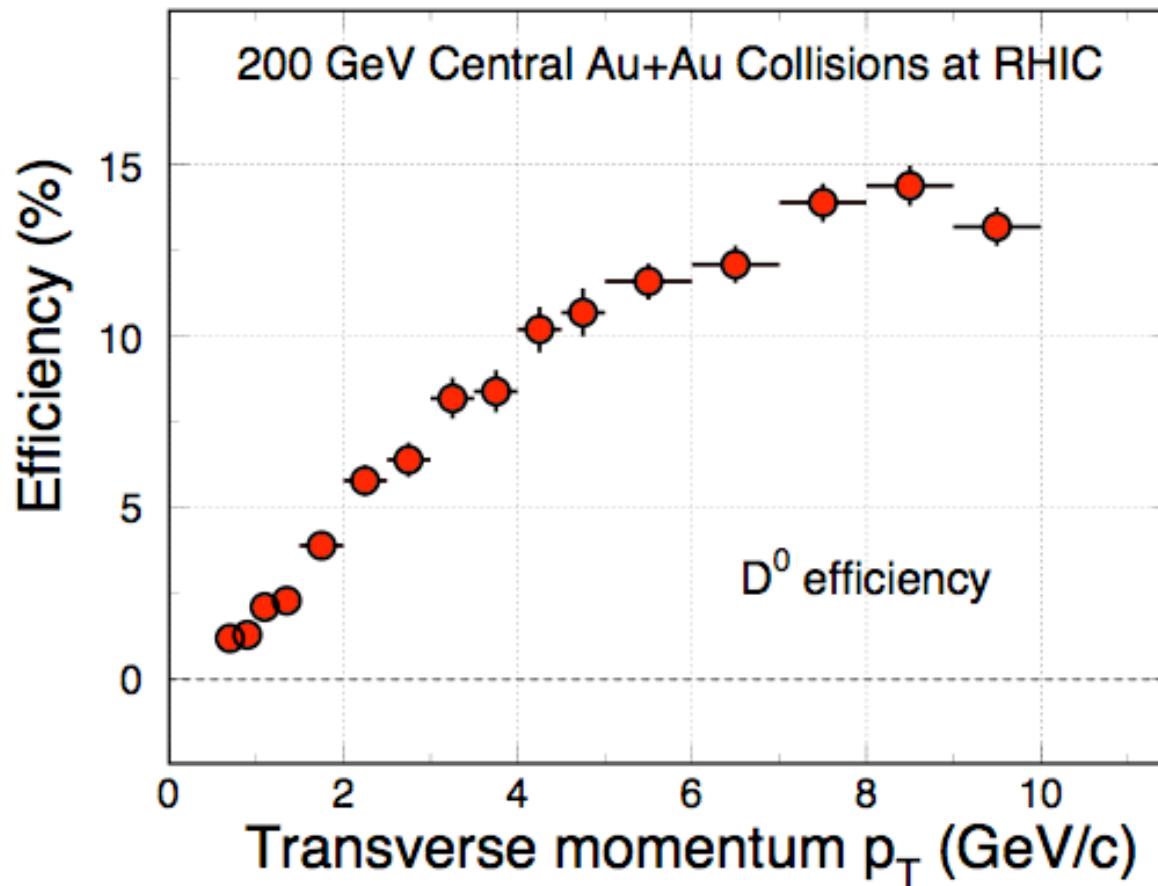
# STAR Detector



# Requirement for the HFT

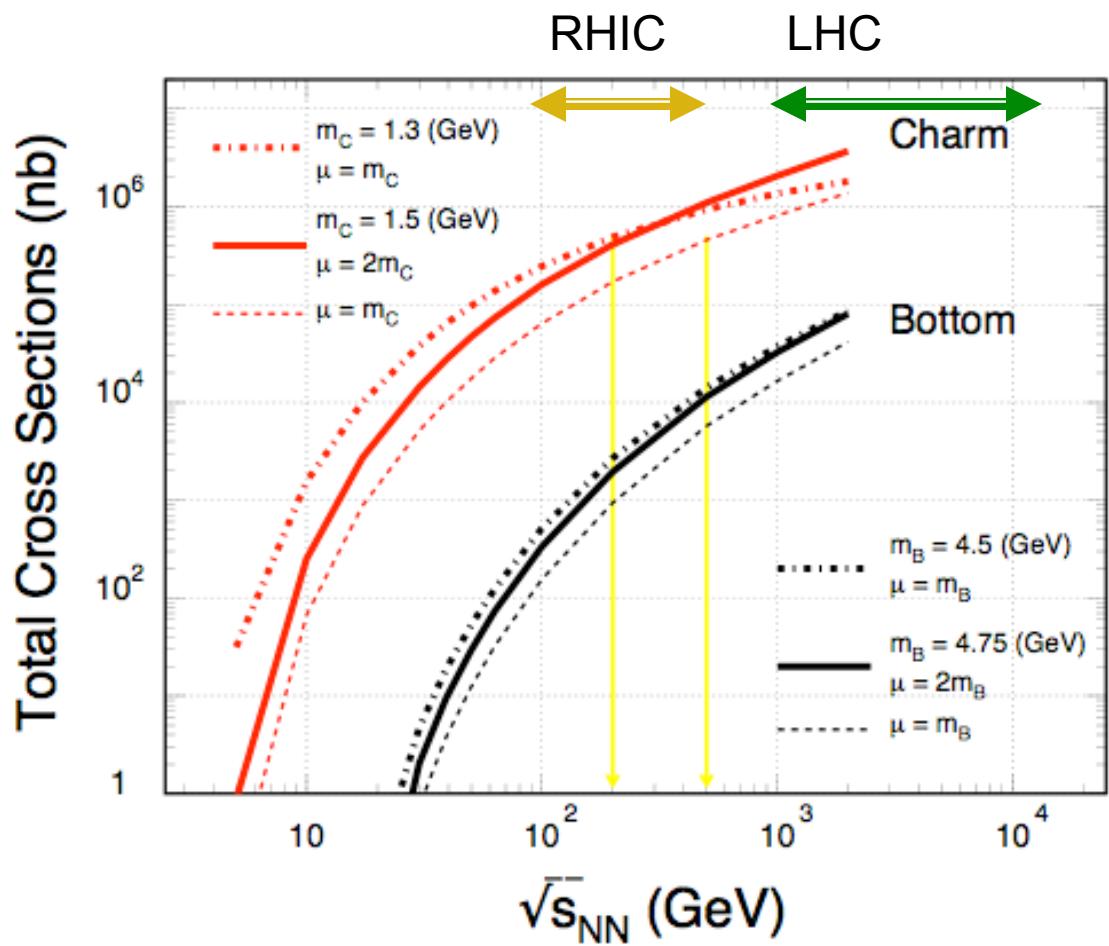
	Measurements	Requirements
Heavy Ion	heavy-quark hadron $v_2$ - the heavy-quark collectivity	<ul style="list-style-type: none"> <li>- Low material budget for high reconstruction efficiency</li> <li>- <math>p_T</math> coverage <math>\geq 0.5 \text{ GeV}/c</math></li> <li>- mid-rapidity</li> <li>- High counting rate</li> </ul>
	heavy-quark hadron $R_{AA}$ - the heavy-quark energy loss	<ul style="list-style-type: none"> <li>- High <math>p_T</math> coverage  <math>\sim 10 \text{ GeV}/c</math></li> </ul>
$p+p$	energy and spin dependence of the heavy-quark production	<ul style="list-style-type: none"> <li>- <math>p_T</math> coverage <math>\geq 0.5 \text{ GeV}/c</math></li> </ul>
	gluon distribution with heavy quarks	<ul style="list-style-type: none"> <li>- wide rapidity and <math>p_T</math> coverage</li> </ul>

# D<sup>0</sup> Reconstruction Efficiency



- Central Au+Au collisions: top 10% events.
- The thin detector allows measurements down to  $p_T \sim 0.5$  GeV/c.
- Essential and unique!

# Heavy Quark Production at RHIC



NLO pQCD predictions of charm and bottom for the total p+p hadro-production cross sections.

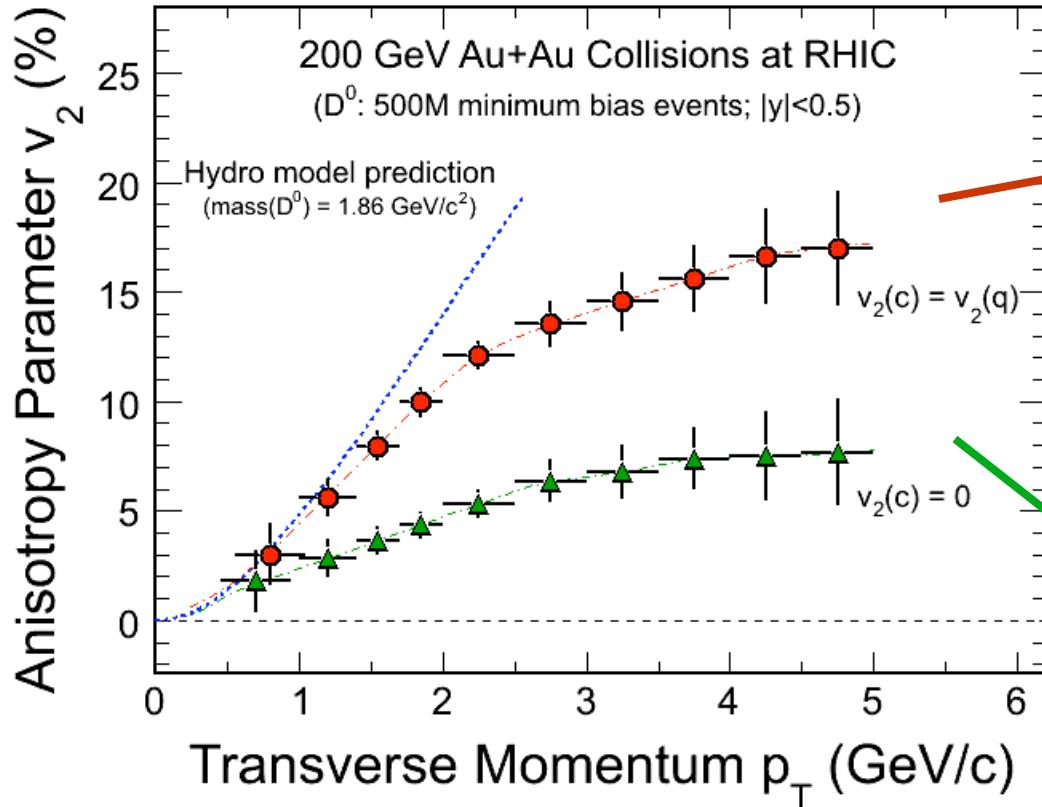
Renormalization scale and factorization scale were chosen to be equal.

**RHIC: 200, 500 GeV**  
**LHC: 900, 14000 GeV**

Ideal energy range for studying pQCD predictions for heavy quark production.

Necessary reference for both, heavy ion and spin programs at RHIC.

# Charm Hadron $v_2$

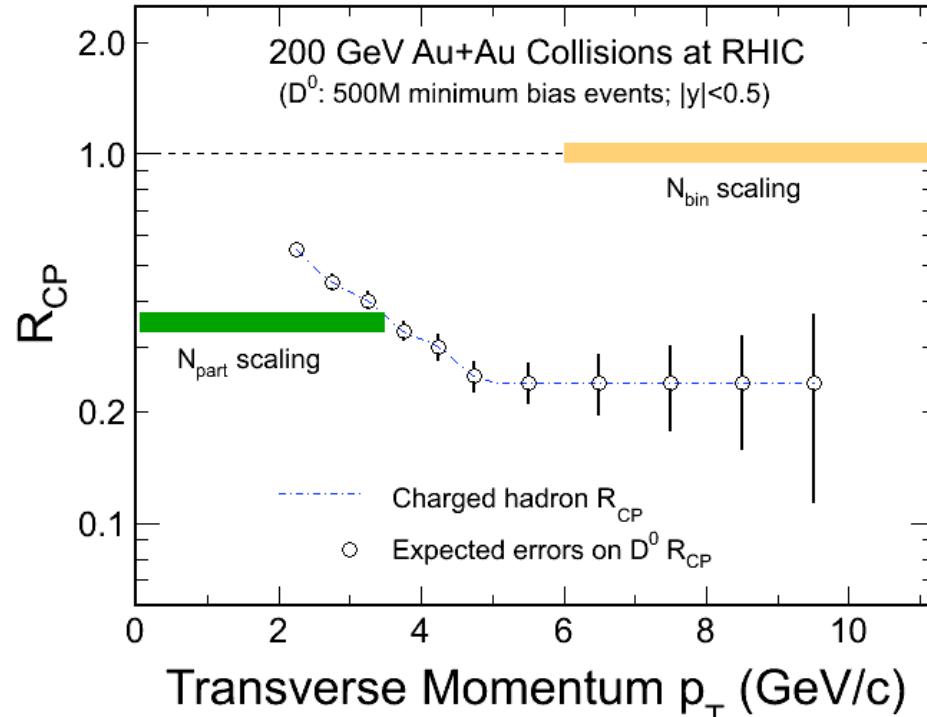
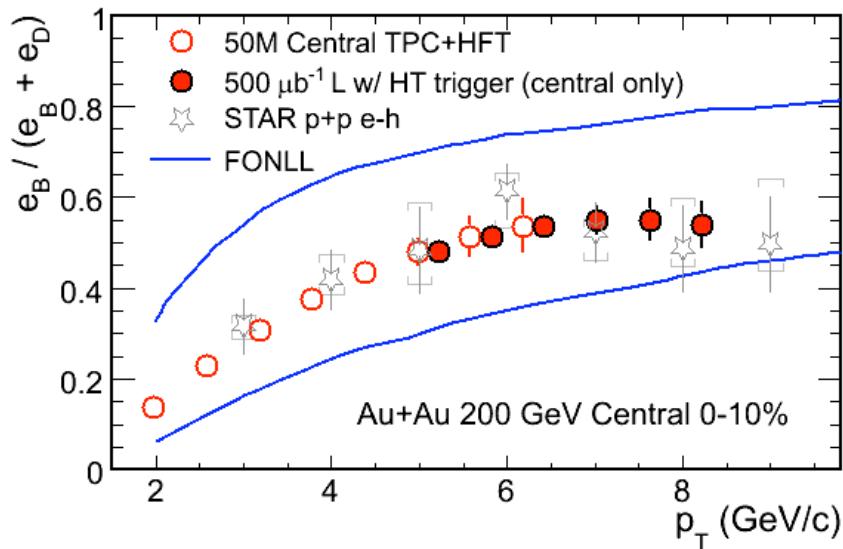


Charm-quark flow  
→ Thermalization  
of light-quarks!

Charm-quark does  
not flow  
→ Drag coefficients

- 200 GeV Au+Au minimum biase collisions (500M events).
- Charm collectivity  $\Rightarrow$  drag/diffusion constants  $\Rightarrow$  **medium properties!**

# Charm Hadron $R_{CP}$



$$R_{CP} = a * N^{10\%} / N^{(60-80)\%}$$

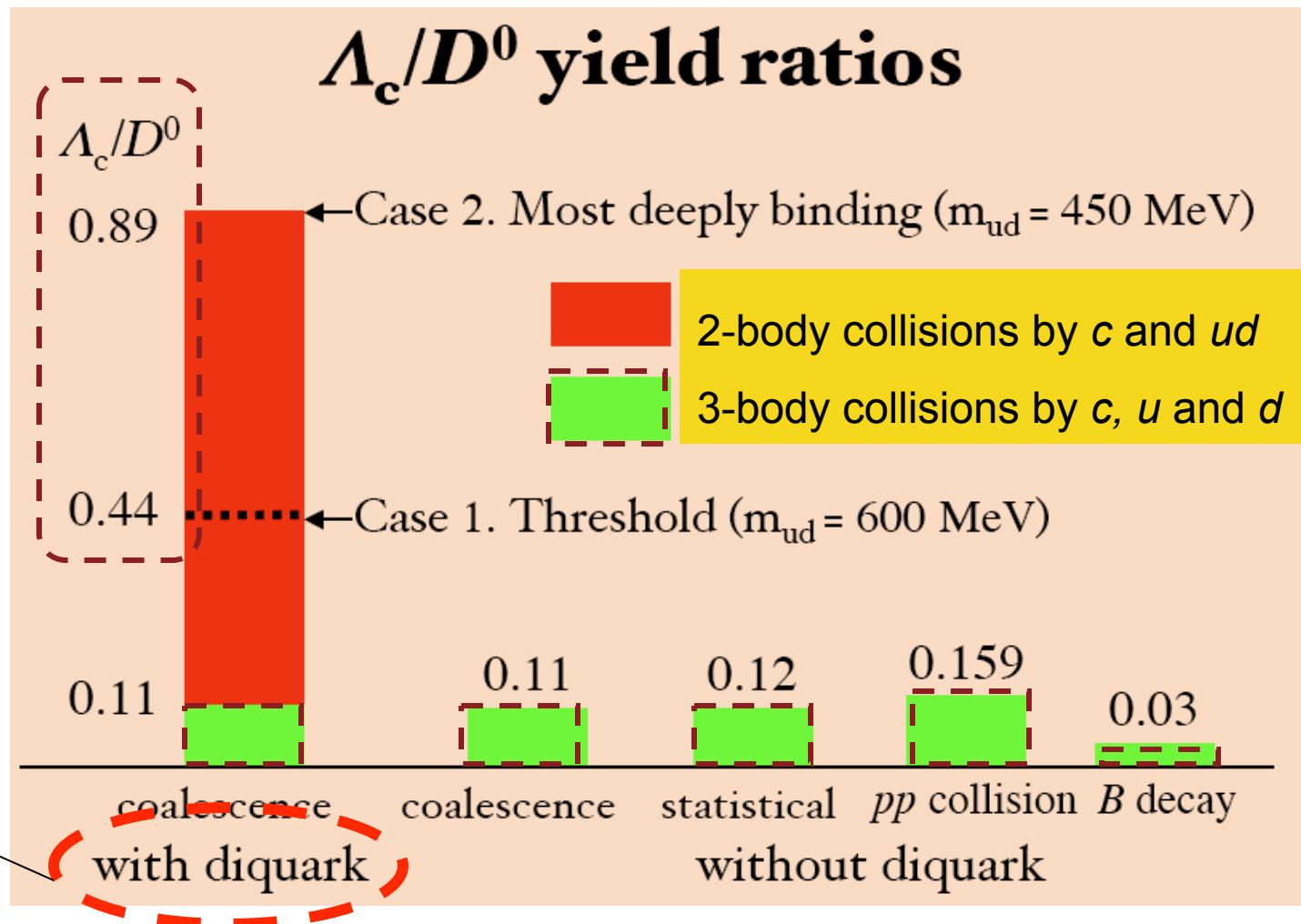
- Significant Bottom contributions in HQ decay electrons.
- 200 GeV Au+Au minimum biased collisions ( $|y|<0.5$  500M events).
- Charm  $R_{AA}$   $\Rightarrow$  **energy loss mechanism!**

# Charm Baryon/Meson Ratios

$$\Lambda_c \rightarrow p K^- \pi^+$$

$$D^0 \rightarrow K^\pm \pi^\mp$$

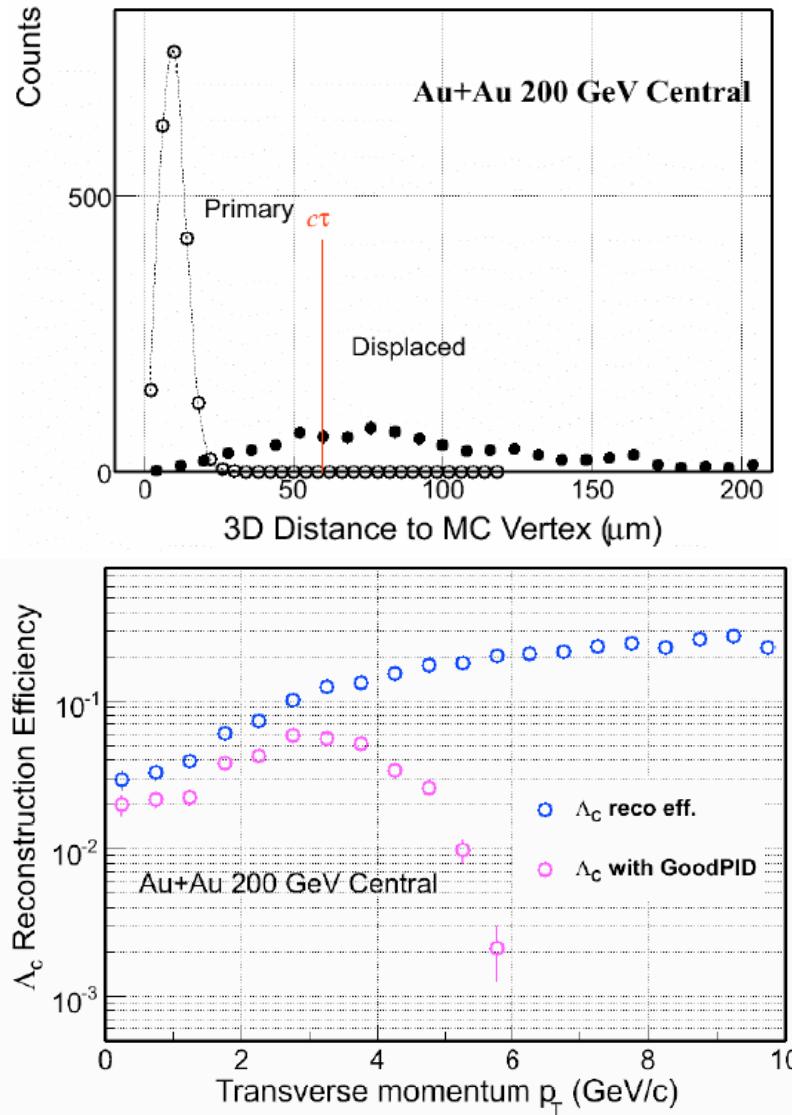
QGP  
medium



Y. Oh, C.M. Ko, S.H. Lee, S. Yasui, Phys. Rev. **C79**, 044905(2009).

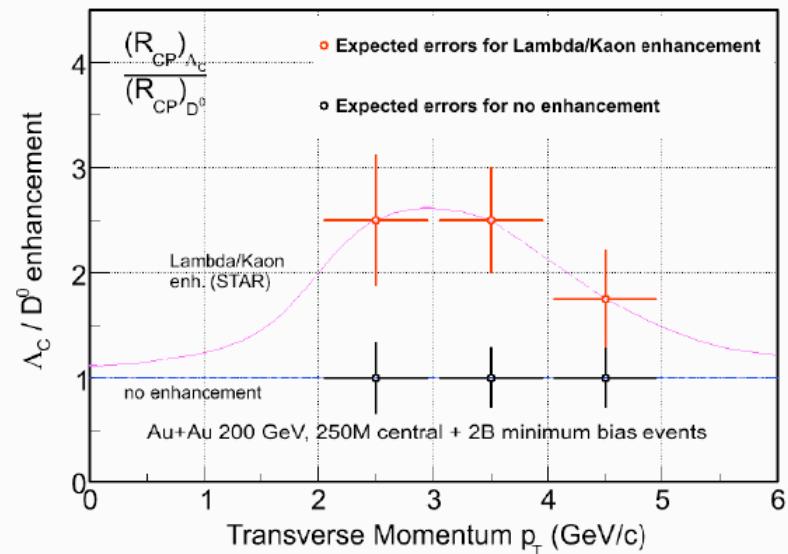
S.H. Lee, K.Ohnishi, S. Yasui, I-K.Yoo, C.M. Ko, Phys. Rev. Lett. **100**, 222301(2008).

# $\Lambda_c$ Measurements

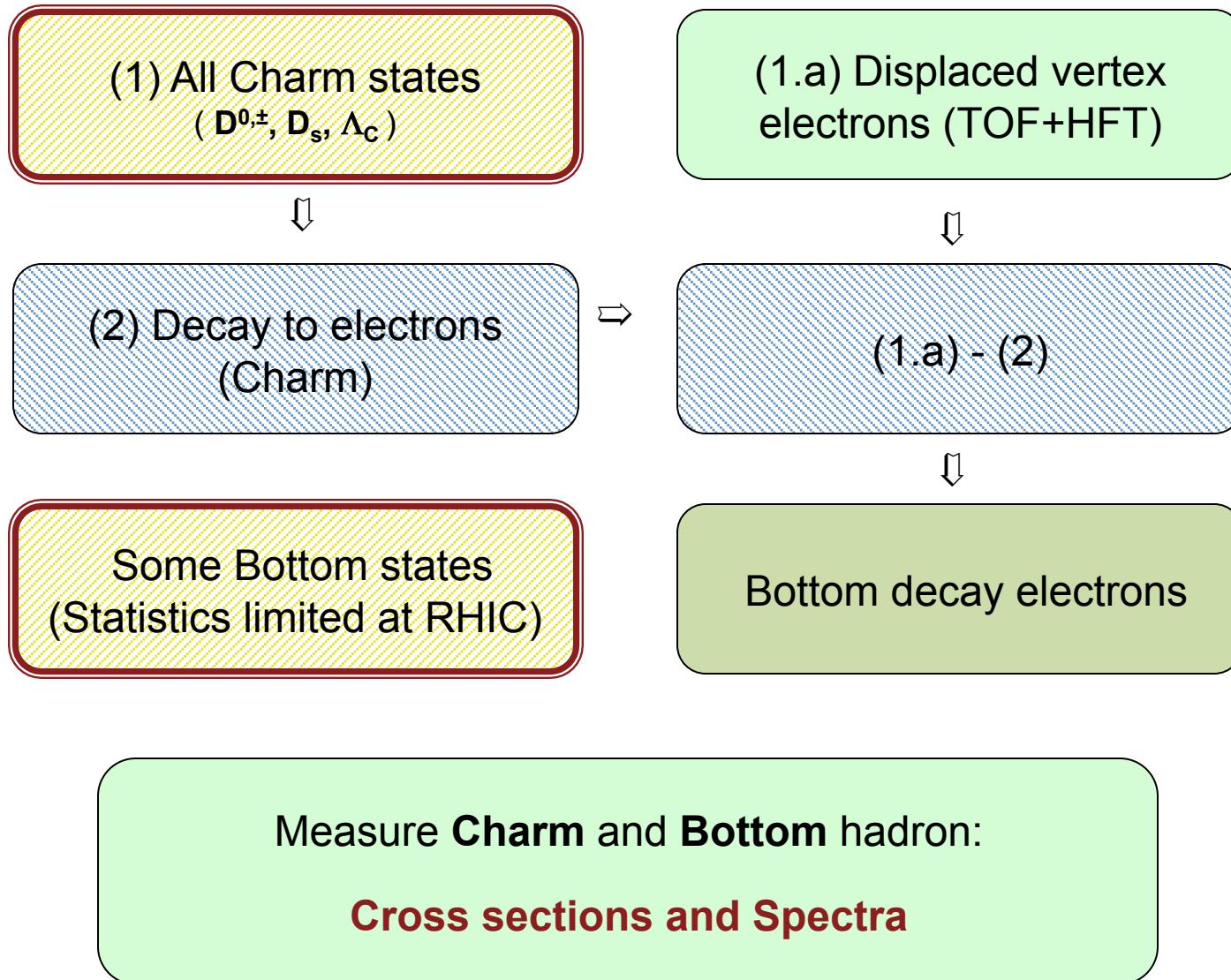


$\Lambda_c (\rightarrow p + K + \pi)$ :

- 1) Lowest mass charm baryon
- 2) Total yield and  $\Lambda_c/D^0$  ratios can be measured.

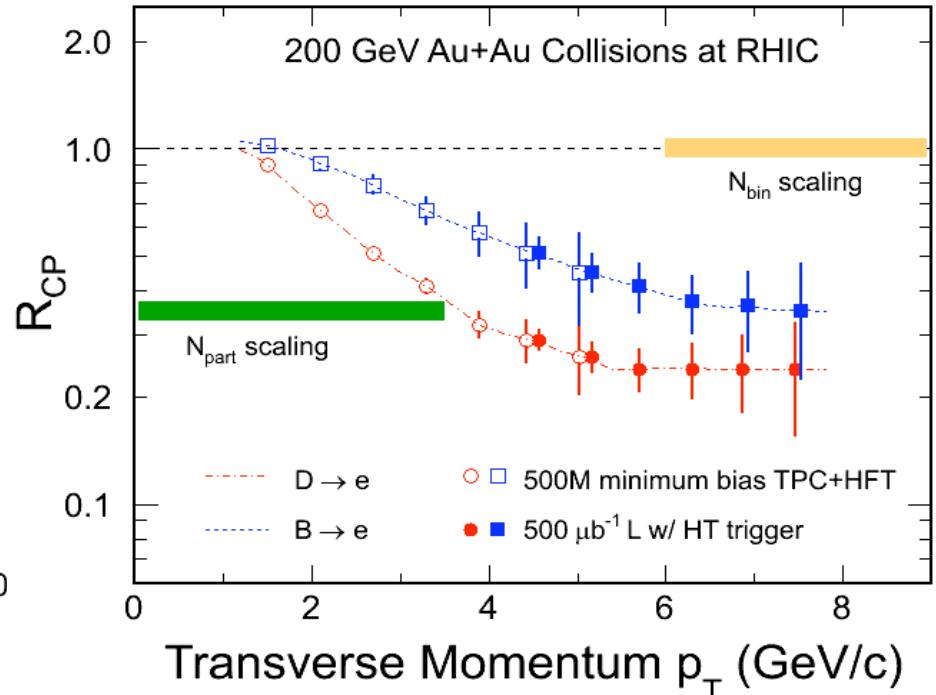
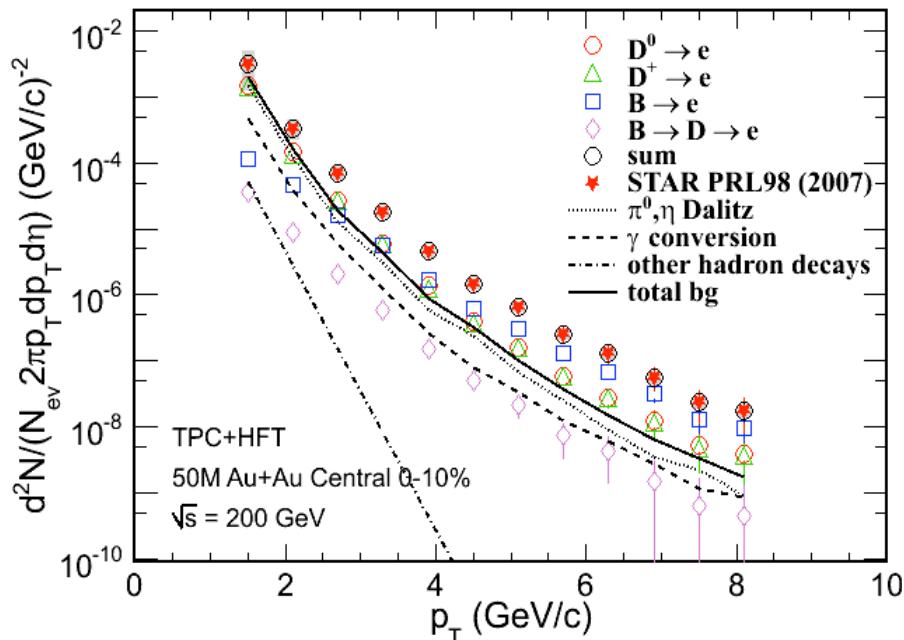


# Strategies for Bottom Measurement



# c- and b-decay Electrons

H. van Hees *et al.* Eur. Phys. J. **C61**, 799(2009). (arXiv: 0808.3710)



$$R_{CP} = a * N^{10\%} / N^{(60-80)\%}$$

- DCA cuts  $\Rightarrow$  **c- and b-decay electron distributions and  $R_{CP}$** .
- 200 GeV Au+Au minimum biased collisions ( $|y| < 0.5$  500M events).

# The di-Lepton Program at STAR

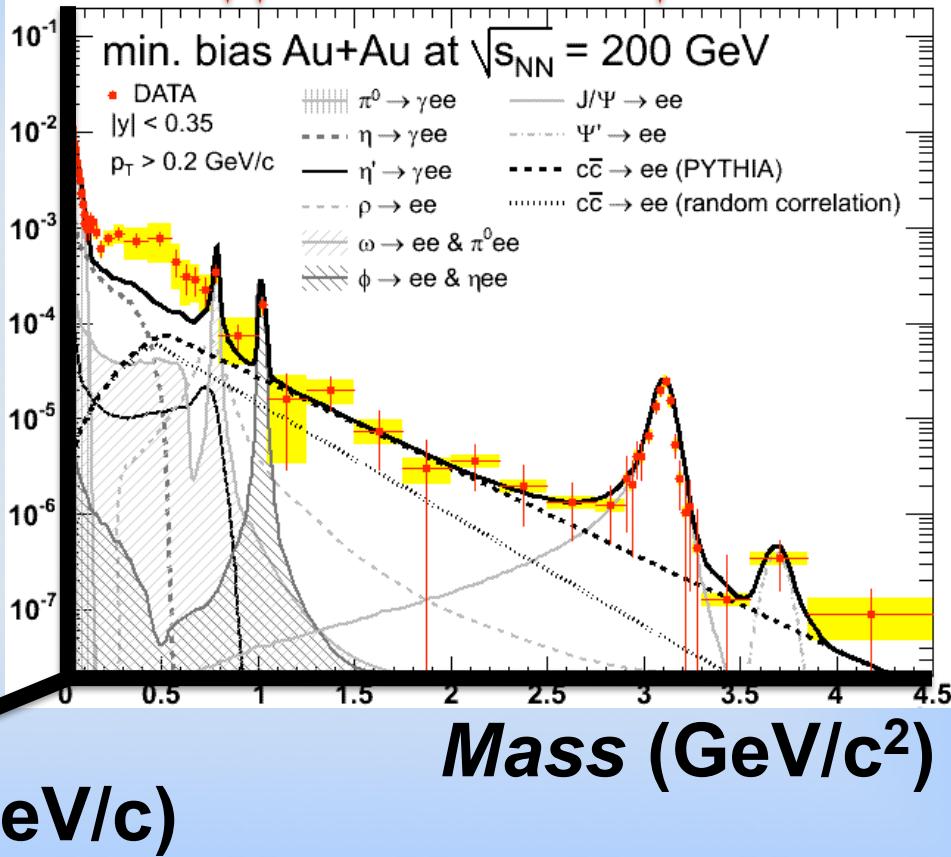
TOF + TPC + **HFT**

- (1)  $\sigma$
- (2)  $V_2$
- (3)  $R_{AA}$

$\rho \phi$

DY, charm Bk

$J/\psi$



✓ Direct radiation from the Hot/Dense Medium

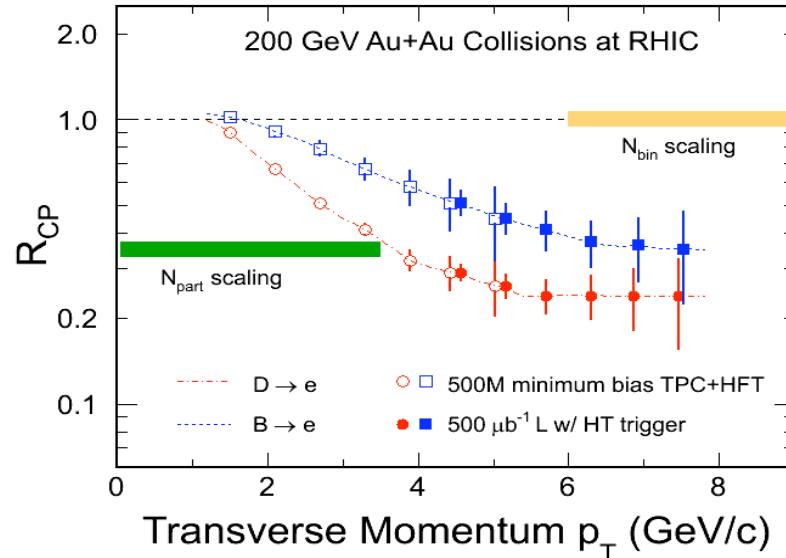
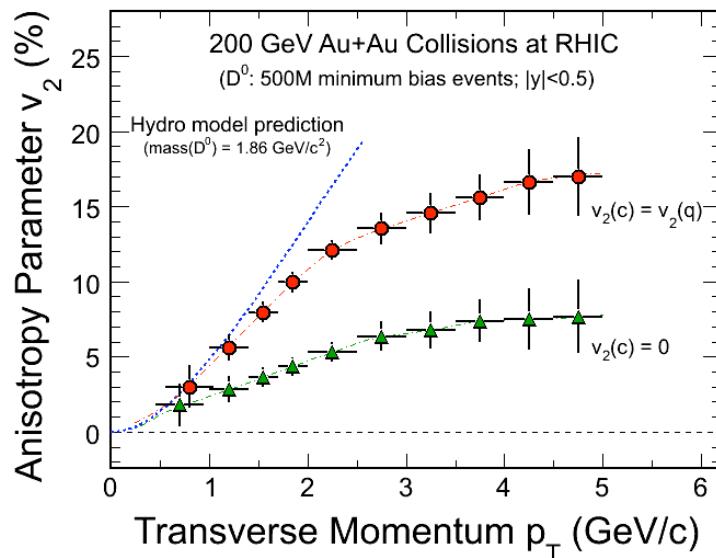
✓ Chiral symmetry Restoration

⇒ A robust di-lepton physics program extending STAR scientific reach

# Physics of the Heavy Flavor Tracker at STAR

## 1) The STAR HFT measurements (p+p and Au+Au)

- (1) Heavy-quark cross sections:  $D^{0,\pm,*}$ ,  $D_S$ ,  $\Lambda_C$ ,  $B\ldots$
- (2) Both spectra ( $R_{AA}$ ,  $R_{CP}$ ) and  $v_2$  in a wide  $p_T$  region: 0.5 - 8 GeV/c
- (3) Charm hadron correlation functions
- (4) Full spectrum of the heavy quark hadron decay electrons

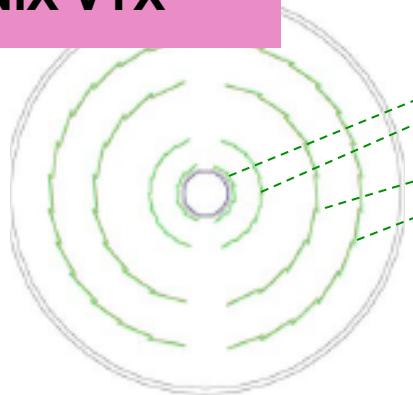


# **Projected Run Plan**

- 1) First run with HFT: 200 GeV Au+Au**  
⇒  $v_2$  and  $R_{CP}$  with 500M M.B. collisions
- 2) Second run with HFT: 200 GeV p+p**  
⇒  $R_{AA}$
- 3) Third run with HFT: 200 GeV Au+Au**  
⇒ Centrality dependence of  $v_2$  and  $R_{AA}$   
⇒ Charm background and first attempt for electron pair measurements  
⇒  $\Lambda_c$  baryon with sufficient statistics



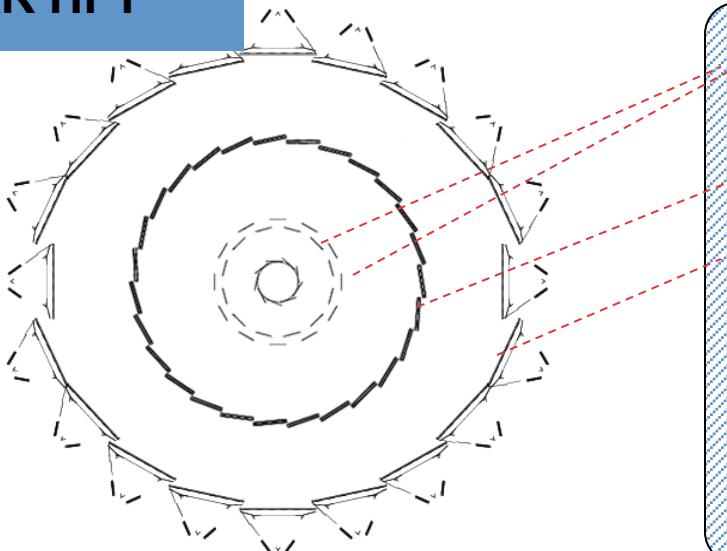
## PHENIX VTX



- 2-layer Si hybrid pixels:  $x/x_0 \sim 0.6\%$ ;  
2.5cm inner radius; fast readout
- 2-layer Si strips,  $x/x_0 \sim 2\%$

$p_T \leq 2$  GeV/c:  $e^\pm$   
 $2 < p_T \leq 6$  GeV/c: D-mesons...  
 $1 < p_T \leq 6$  GeV/c:  $B \rightarrow J/\psi$

## STAR HFT



- 2-layer CMOS:  $x/x_0 \sim 0.37\%$  per layer;  
2.5cm inner radius; 200 $\mu$ s integration
- 1-layer\* Si strips
- SSD:  $x/x_0 \sim 1\%$

$e$ ,  $D^{0,\pm,s,*}$ ,  $\Lambda_c$ ,  $B$ ...  
**Low  $p_T > 0.5$  GeV/c:**  $v_2$ ,  $R_{AA}$   
**D-D correlation functions**